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Abstract

A systematic test of various characteristics, such as gain, dark current, maximum peak current, stability and relative quantum efficiency, has been made to evaluate about 2,000 photomultiplier tubes for the upgraded CDF Endplug calorimeters. The phototubes are Hamamatsu R4125, 19mm diameter with green-extended photocathode. In this report we discuss the distribution of the major characteristics measured and the failure mode. Comparisons between independent measurements made on some of the characteristics are used to evaluate the quality of the measurement itself.

[a]Talk given at the VII Conference on Calorimetry in HEP, Tucson AZ, Nov.10-15 1997.

1 Introduction

The upgraded Endplug calorimeters for the CDF experiment [1] use as active elements scintillator tiles with embedded WLS fibers (Y11) spliced to clear optical fibers at the tile exit. Calorimeters are segmented into projecting towers pointing at polar angles ranging from $\theta = 37°$ to $3°$ (η from 1.1 to 3.6) measured from the beam line. Electromagnetic (EM) and Hadronic (HAD) sections have similar geometry and are read out separetely. One photomultiplier tube is optically coupled (through a plexiglass light mixer) to the fibers boundle from each tower (EM or HAD), it integrates the light signals ($\lambda_{peak} = 480nm$) from the 22 tiles in the tower. Phototubes are housed into some temperature controlled boxes placed on the rear of the detectors. A total of 960 phototubes for the EM sections plus 846 for the HAD sections is needed.

2 Physics Requirements

The operative parameters of the CDF experiment for the next run ($\mathcal{L} = 2 \times 10^{32} cm^{-2} s^{-1}$, beam crossing time as low as $132ns$, $E_{cm} = 2TeV$, $\int \mathcal{L} \simeq 2fb^{-1}$) translate into some physics requirements that constrain our phototube specifications.
For the highest η towers we expect [b]:

- a maximum energy deposit from a single particle initiated shower of $770GeV$ for the EM, $600GeV$ for the HAD, which translates into a maximum peak current of $55mA$ and $35mA$ respectively when the phototubes are operated at the nominal voltages (2.5×10^4 EM, 2.5×10^5 HAD);
- an energy flow due to the underlying event of $250MeV$/interaction in the HAD (about half of it for the EM) which produces a quasi-DC background current of about $1\mu A$ out of the phototube (almost the same for the EM and HAD);
- an accumulated anodic charge of about 10 C.

3 Phototube Choice

After comparative tests on few samples of candidate phototubes [2] we chose the *Hamamatsu R4125* being the one that better fulfilled our overall requirements. It is a 10 stages tube with a $19mm$ outer diameter and $15mm$ diameter photocathode. It has a green-extended bialkali photocathode with a certified quantum efficiency of 12% at $\lambda = 480nm$. In the preliminary tests it showed a

[b] Calculations are based on extrapolation of the tower energy deposits from the previous CDF run and on the design values for the number of photoelectrons/GeV/tile and the shape of the phototube signal. The numbers obtained from the recent calorimeters test beam results are slightly lower.

good photocatode uniformity (at a 20% level) and behaved well in the lifetime test (the decrease of response for 100C of integrated charge being 12% on average). Bases of resistive chain type where designed at Fermilab and built by Thorn EMI Corporation.

4 Test Procedure

A total of 2,100 R4125 phototubes were purchased. For each one the vendor provided us with a measurement of the voltage and the dark current for a nominal gain of 500K and both the cathode blue and luminous sensitivity.
In our laboratories each phototube underwent a full test procedure that consisted of two phases called "initial test" and "final test". The "initial test" was performed at Fermilab for all of the tubes, the "final test" was performed at one of two test sites (INFN lab. Bologna-Italy (820 tubes) and Fermilab (1280 tubes)) were two identical test setups were built. For the "initial test" each tube/base combination had its gain versus voltage behaviour measured, then it was conditioned for 48 hours by exposure to a steady-state LED light producing a $2\mu A$ anode current. Finally a dark current measurement was made. For the "final test" a number of tests were performed on each tube/base combination: Gain vs Voltage, Dark Current, Linearity, Stability vs Time and Stability vs Background Current Change (in this time sequence). Relative Quantum Efficiency was measured at Fermilab on 10% of the phototubes.

5 Test Setup

Our test setups consist of a light-tight temperature-controlled box that can house up to 30 tubes for testing. Three kind of light sources are used to independently excite the phototubes to which are coupled through clear optical fibers: an array of pulsed red LEDs (for the gain measurements), an array of stady-state green LEDs (to provide the background current) and a pulsed UV laser (for the linearity and stability measurements). The laser light, monitored by a PIN diode, is carried to a *cow distributor system*[3] where it is wavelenght shifted into green and distributed to the phototubes. In this way the tubes are tested with light pulses that closely match the real calorimeter signals. Tests are carried on in a quasi-automated way by a PC controlled CAMAC/NIM DAQ system.

6 Measurements and Results

6.1 Gain vs Voltage

For each phototube the gain was measured with statistical method[2] at various voltages (from 700V to 1800V at 100V steps). Data points were fitted with a linear function on a double logarithmic scale ($\log G = K + P \times \log V$), the parameters of the fit allow to calculate the tube voltage for any given gain. In fig.1 for each phototube the voltages to get four different gains are plotted. A comparison is made between the two re-measurements done in the initial (all measurement done with the Fermilab setup) and final test (measurements done at Fermilab or Bologna). The distribution of the ratios shows that the overall quality of our measurements is satisfactory having a spread around 1. (FWHM/mean) of about 7%. Our measurement also does correlate well to the voltage value provided by Hamamatsu, the 8% offset being due to a difference in the gain measuring method used.

6.2 Dark Current

Similarly in fig.2 a comparison is made between our initial and final measurements and the vendor measurement of the phototubes dark current at a gain of 500K. A decrease in the dark currents of about a factor of two is found between Hamamatsu and our initial measurement probably due to the conditioning and the exercising of the tubes during the tests. Very few tubes fail the $5nA$ specified limit. The final average value for the dark current at G=500K is 0.43 nA.

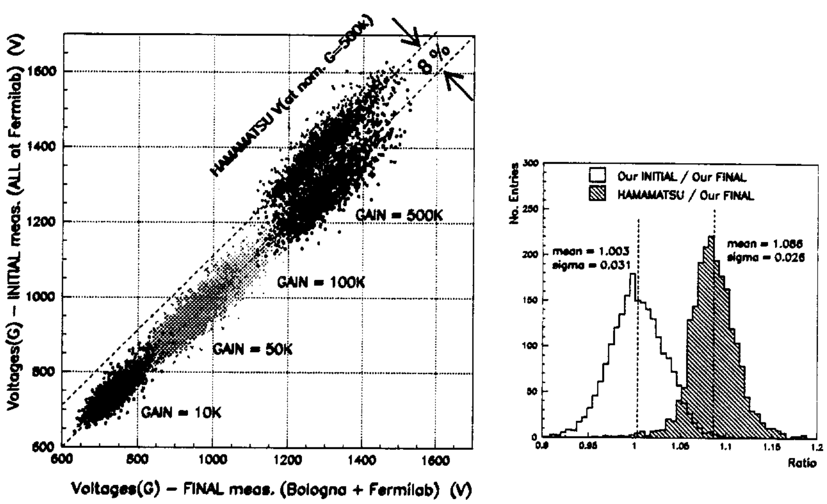

Figure 1: Comparison between independent measurements of all tubes Voltages at four different Gains.

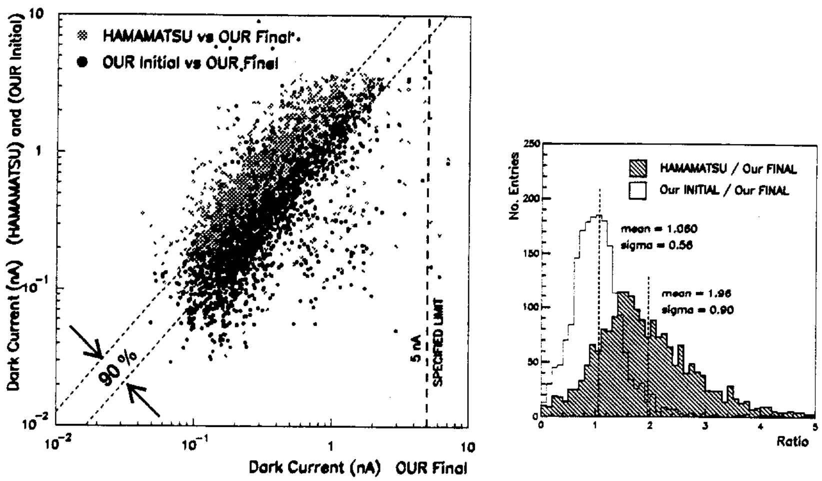

Figure 2: Comparison between independent measurements of all tubes Dark Currents. The log-log scale emphatizes the small values region where most of the data gather.

6.3 Linearity

The linearity behaviour of the tubes response with the intensity of the input light signal was measured at four gain values. The figure of merit is the value of the anode peak current that can be reached within a 2% deviation from linearity. Results and specified limits for the peak currents are summarized in table 1. We found a fraction of 1.7% of the phototubes failing the test at the highest gain.

Table 1: Linearity test results.

Gain	Peak Curr. Measured Range	for 2% deviation		No. of tubes Rejected	% of tubes Rejected
		Specified Lower Limit	Peak Curr. Mean Value*		
10 K	up to 40 mA	10 mA	16.5 mA	3	0.1
50 K	up to 90 mA	20 mA	44.0 mA	2	0.1
100 K	up to 100 mA	35 mA	74.3 mA	3	0.1
500 K	up to 160 mA	70 mA	93.5 mA	35	1.7

* for tubes that showed > 2% deviation within the measured range (about 50% of total)

Based on these measurements higher linearity phototubes are assigned to higher η calorimeter towers. In fig.3 the maximum peak current is converted into energy deposit per tower (for one EM section) using the conversion factor measured at the test beam.

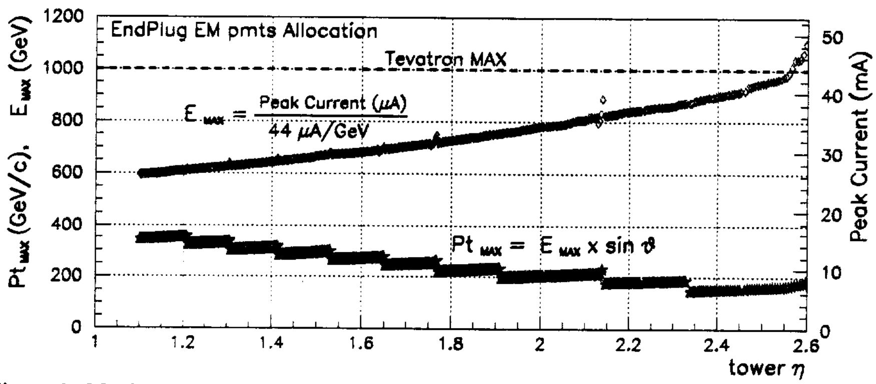

Figure 3: Maximum energy and transverse momentum that can be deposited in each η EM calorimeter tower within 2% from linearity.

6.4 Stability with Time

The variation in the response to pulsed light was measured over a 72 hours period while the phototubes were exposed to a steady-state green light. The figure of merit is the maximum percent variation in 48 hours which must be less than 6%. 48 hours is the expected maximum duration of a Tevatron store for the next run. On average the response of the tubes decreases of about 2% in a 48 hours time, a fraction of 2.7% of the tubes failed the test.

6.5 Stability with Background Current Change

We measured the percent shift of the tubes response when the background DC current was changed from zero to about $1\mu A$. This mimic the situation the higher η phototubes will experience when the proton beams in the Tevatron start colliding.

We found about half of the tubes having a positive shift value (+1.9% on average), the other half having a negative value (-1.3% on average). A fraction of 2.3% of the sample had an absolute value of the shift greater than 5%, our specified limit for this test.

6.6 Relative Quantum Efficiency

The measurement was done, for a monitoring purpose, on the 3 tubes out of every 30 that had the lowest rated value for the blue cathode sensitivity. It consisted in measuring the number of photoelectrons produced at the tube photocathode by a standard tile/fiber combination to which the tube was optically coupled in a very reproducible way [2].

In fig.4 we compare our measurements of relative Q.E. with the cathode sensitivity values from Hamamatsu. A good correlation is found (a,c). The cathode blue sensitivity shows little fluctuations with manufacturing date (c). The shape of the distribution for our measurements and the chatode blue sensitivity (rescaled) is in good agreement too (b). Even if our is a relative measurement of Q.E. we have actually measured the spread of the Q.E. values around the mean value being 23%.

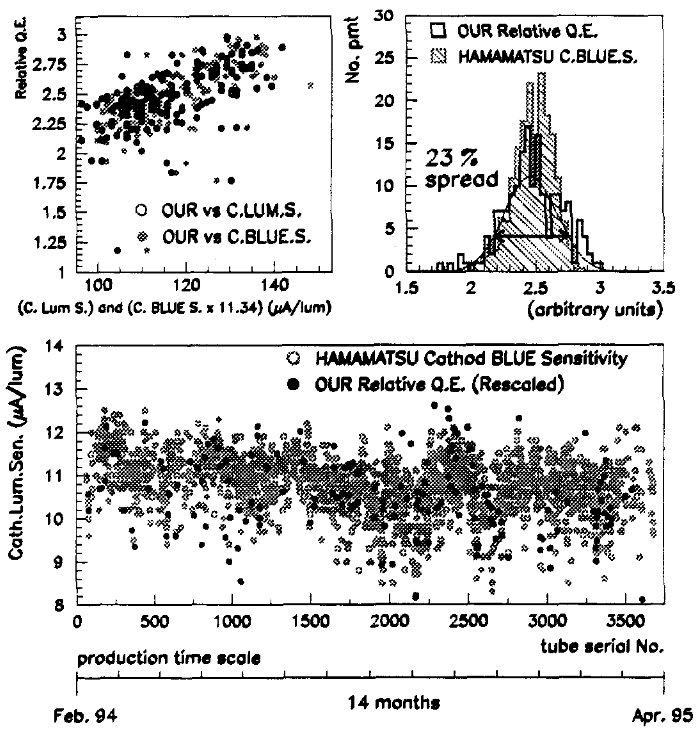

Figure 4: (a) Scatter plot of our Relative Q.E. measurements vs Hamamatsu values for Cathode Blue and Lum. Sens. (b) Our Relative Q.E. measurements and Hamamatsu C. Blue S. rescaled with the ratio of the mean values of the two. (c) Hamamatsu C. Blue S. vs manufacturing time, our rescaled Relative Q.E. are superimposed.

7 Summary and Conclusions

We have made extensive measurements on 2,100 Hamamatsu R4125 phototubes for the CDF Endplug calorimeters. We have measured the following properties: Gain vs Voltage, Dark Current, Linearity, Stability vs Time and vs Background Current. Some were measured twice for each phototube. Results

Table 2: Other tests results.

TEST	Selection Criteria	Specified Limit	Mean Value	N. of Rej.	% of Rej.
Gain vs Voltage	Voltages spread at G=500K	$< 20\%$	11.5%		
Dark Current	D.C. value at G=500K	< 5nA	.43nA	5	0.2
Stability with time	% Deviation in 48 hours	$< 6\%$	2.2%	55	2.7
Stab. with bkg current	% Shift for $\Delta I_{bkg} = 1\mu A$	$< 5\%$	1.7%	48	2.3

are summarized in tables 1 and 2.

- Those characteristics that were measured twice show good agreement.
- Measurements taken at three test sites (Hamamatsu, Bologna and Fermilab) are well correlated.
- The phototubes show little variation in major properties with manufacturing date.
- A fraction of 7.5% of the phototubes failed at least one of our selection criteria.
- The phototubes that pass all tests have properties that tipically are well within our specified limits.

Acknowledgments

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